Coherent radio precursors to neutron star mergers

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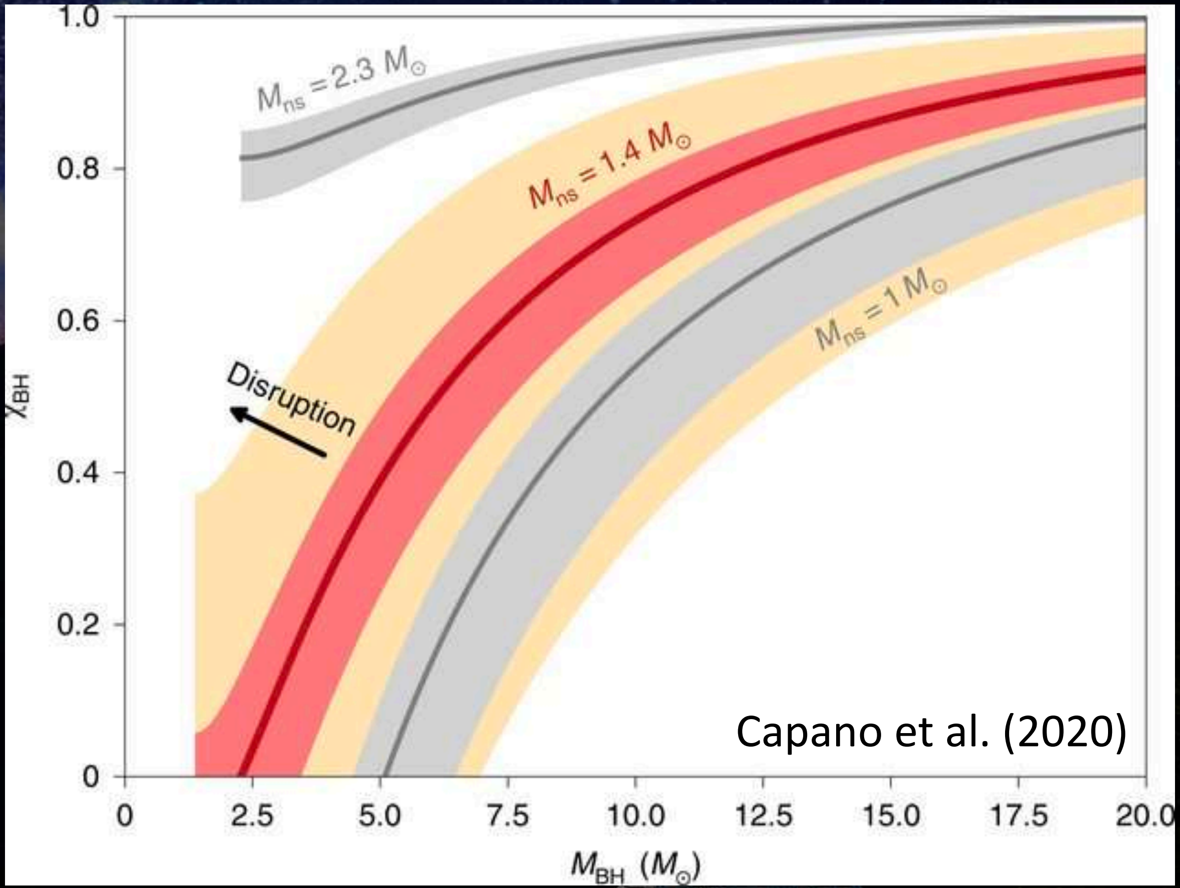
Navin Sridhar

With: Brian Metzger, Jonathan Zrake, Lorenzo Sironi, Dimitrios Giannios

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Need for a ‘precursor’

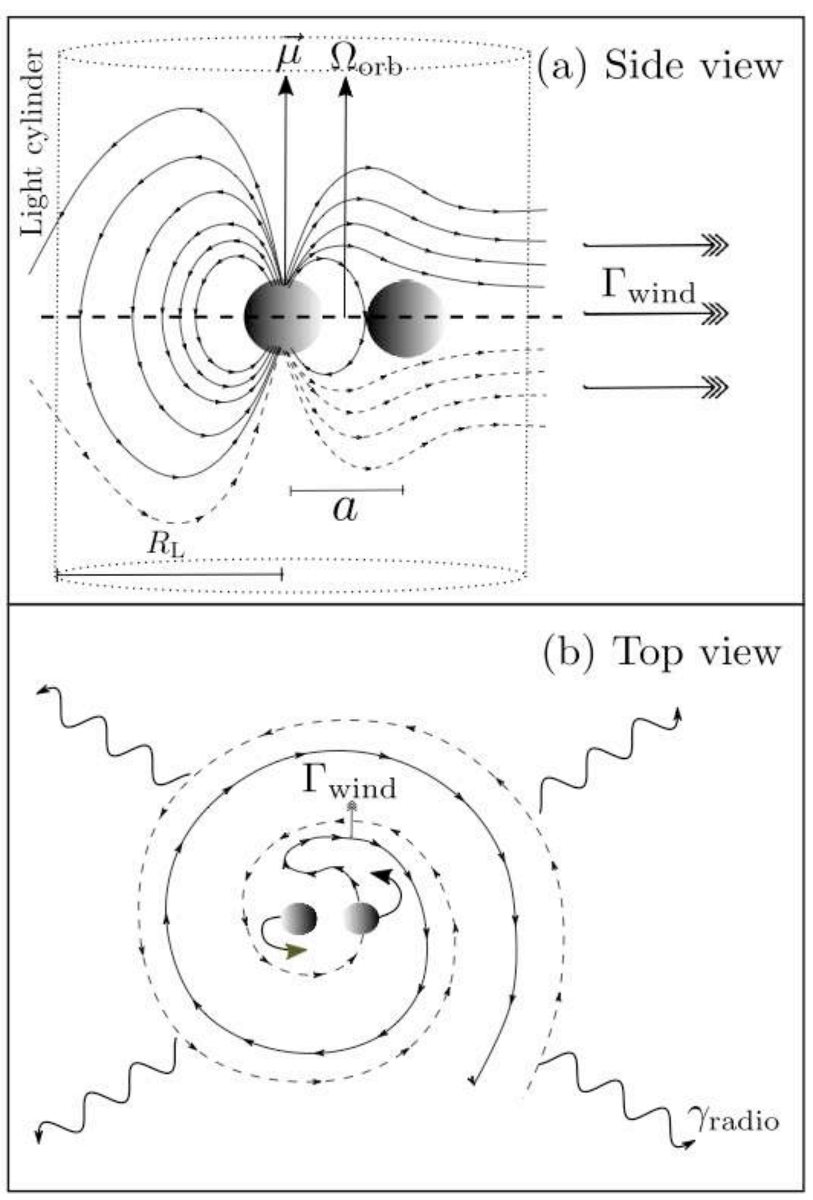
- Learn before destruction
- Harbinger to enable prompt EM follow-up of post-merger emission.
- Drawback of GRBs: Beaming
- Massive BH-NS or NS-NS with dim or non-existent post-merger counterparts.
- Millisecond duration radio burst (final few orbits of the binary) could resemble fast radio bursts (FRBs)?

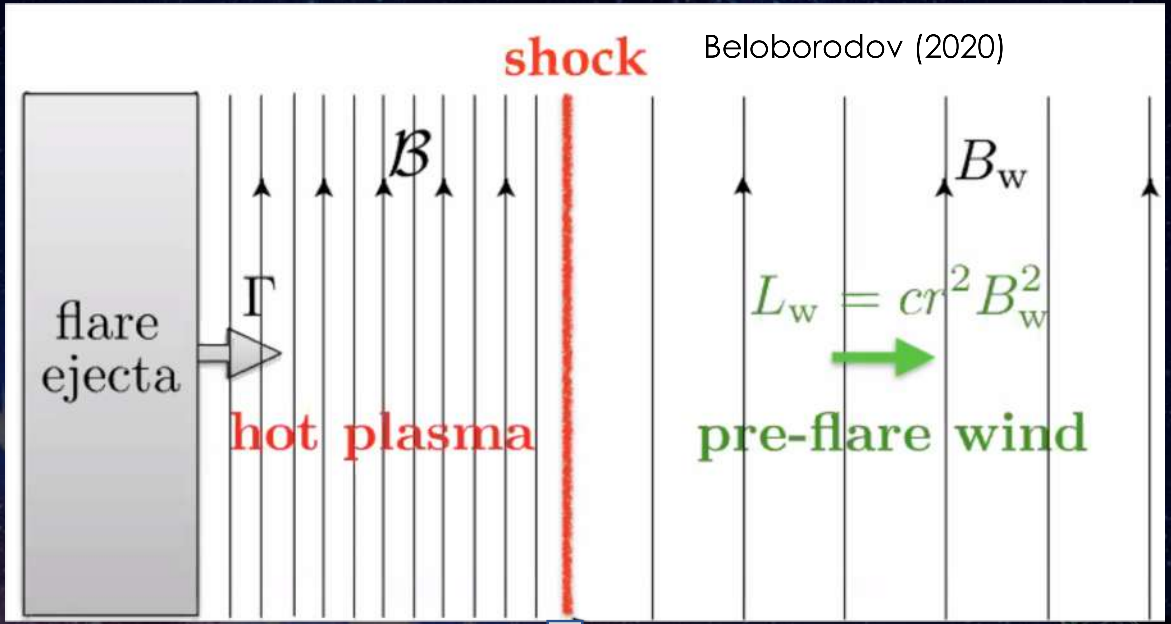


Capano et al. (2020)

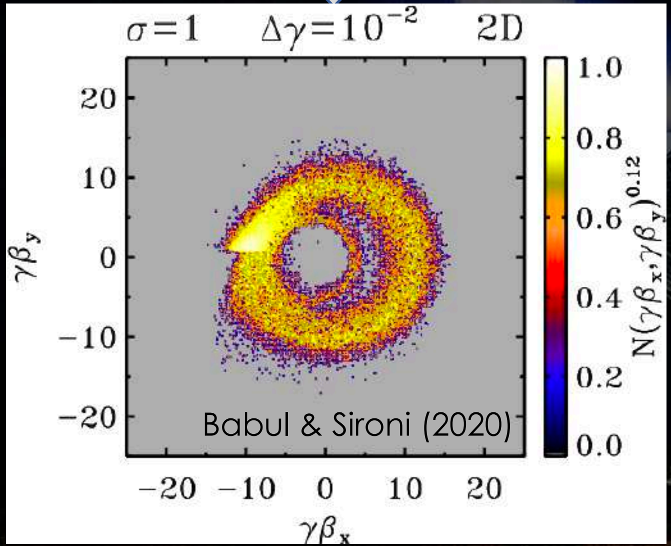
Mechanism

- At least one NS is magnetized.
- Field lines of the strongly magnetized star is opened by a resistive companion (e.g., BH).
- Orbital acceleration of the primary → powers the dipole radiation (independent of companion).
- A fraction of the power is dissipated by heating particles, and the rest in the form of Poynting flux along <u>*open field lines*</u>.
- The accelerating magnetized wind ‘ejecta’ creates internal shocks in the binary plane → synchrotron maser instability.





- Larmor gyration at shock front; unstable soliton-type structure
- Circle in momentum-space, collapses and radiates



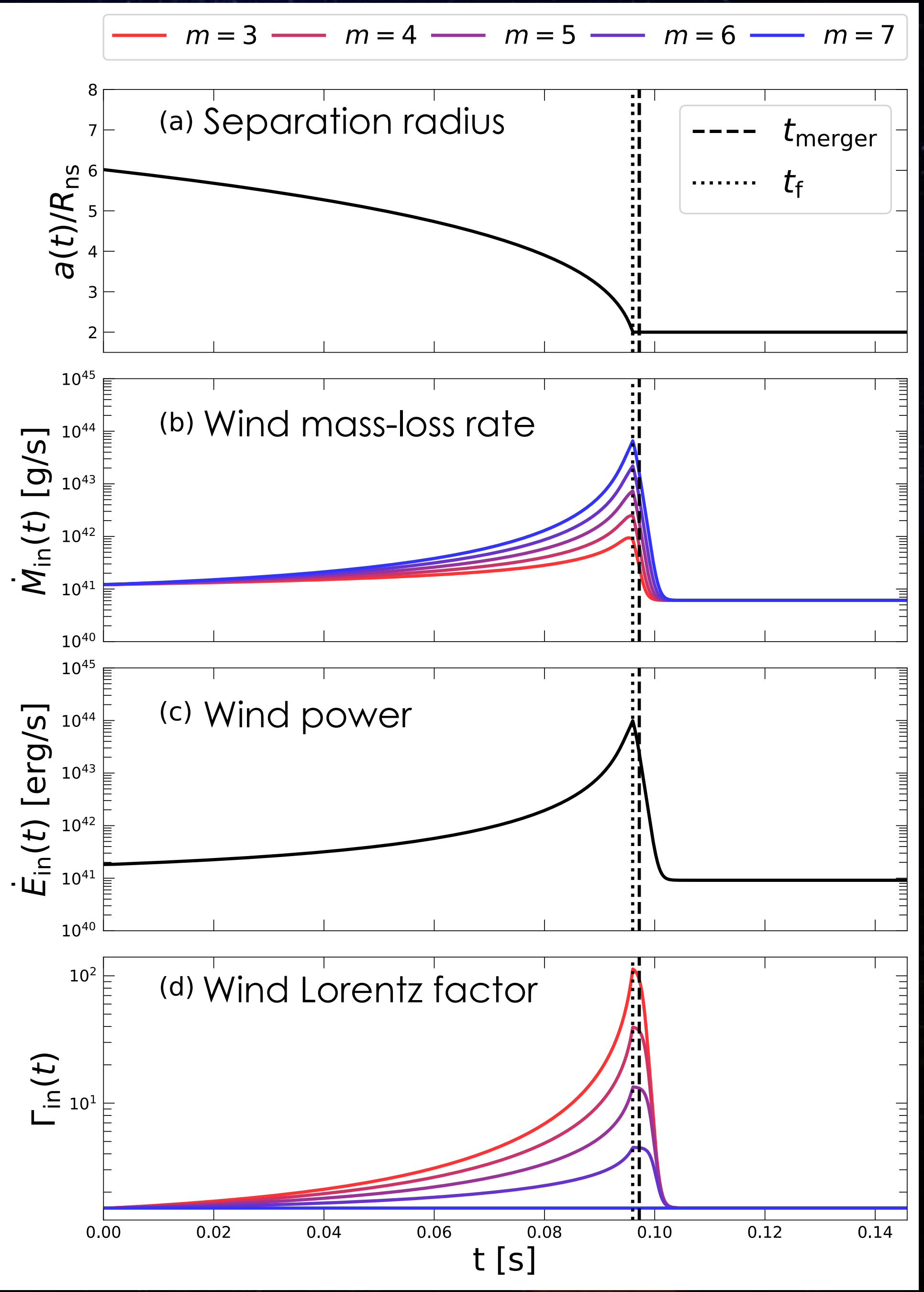
Wind calculations

- The power of the binary wind $\dot{\mathrm{E}} = \left(\frac{\mathrm{f}_\Phi}{\tilde{\mathrm{f}}_\Phi}\right)^2_{\mathrm{bin}} \frac{\mu^2 \Omega^4_{\mathrm{bin}}}{\mathrm{c}^3} \approx 3\times10^{44} \mathrm{erg\ s^{-1}} \left(\frac{\mathrm{B_d}}{10^{12}\mathrm{G}}\right)\left(\frac{\mathrm{a}}{\mathrm{R_{NS}}}\right)^{-7}$
- GW-coalescence time $\mathrm{t_m} = \frac{5}{512} \frac{\mathrm{c}^5 \mathrm{a}^4}{\mathrm{G}^3 \mathrm{M}^3_{\mathrm{NS}}} \approx 1.2\times10^{-3} \left(\frac{\mathrm{a}}{24\ \mathrm{km}}\right)^4.$
- Wind mass-loss rate $\dot{\mathrm{M}}_{\mathrm{GJ}} \approx \frac{\mu_\pm}{\mathrm{e\ c}} \frac{4\mu\mathrm{G}\mathrm{M_{NS}}\mathrm{m_e}}{\mathrm{a}^3}$. We parametrize it as $\dot{\mathrm{M}} \propto \mathrm{a}^{-\mathrm{m}}$.
- A wind that converts its total (magnetic + kinetic) energy to fully kinetic* can have its Lorentz factor given by $\Gamma(\mathrm{t}) = \frac{\dot{\mathrm{E}}(\mathrm{t})}{\dot{\mathrm{M}}(\mathrm{t})\mathrm{c}^2} \propto \mathrm{a}^{\mathrm{m}-7}; (3 \leq m < 7)$.

* Assuming that the 'σ-problem' is solved.

Wind profiles

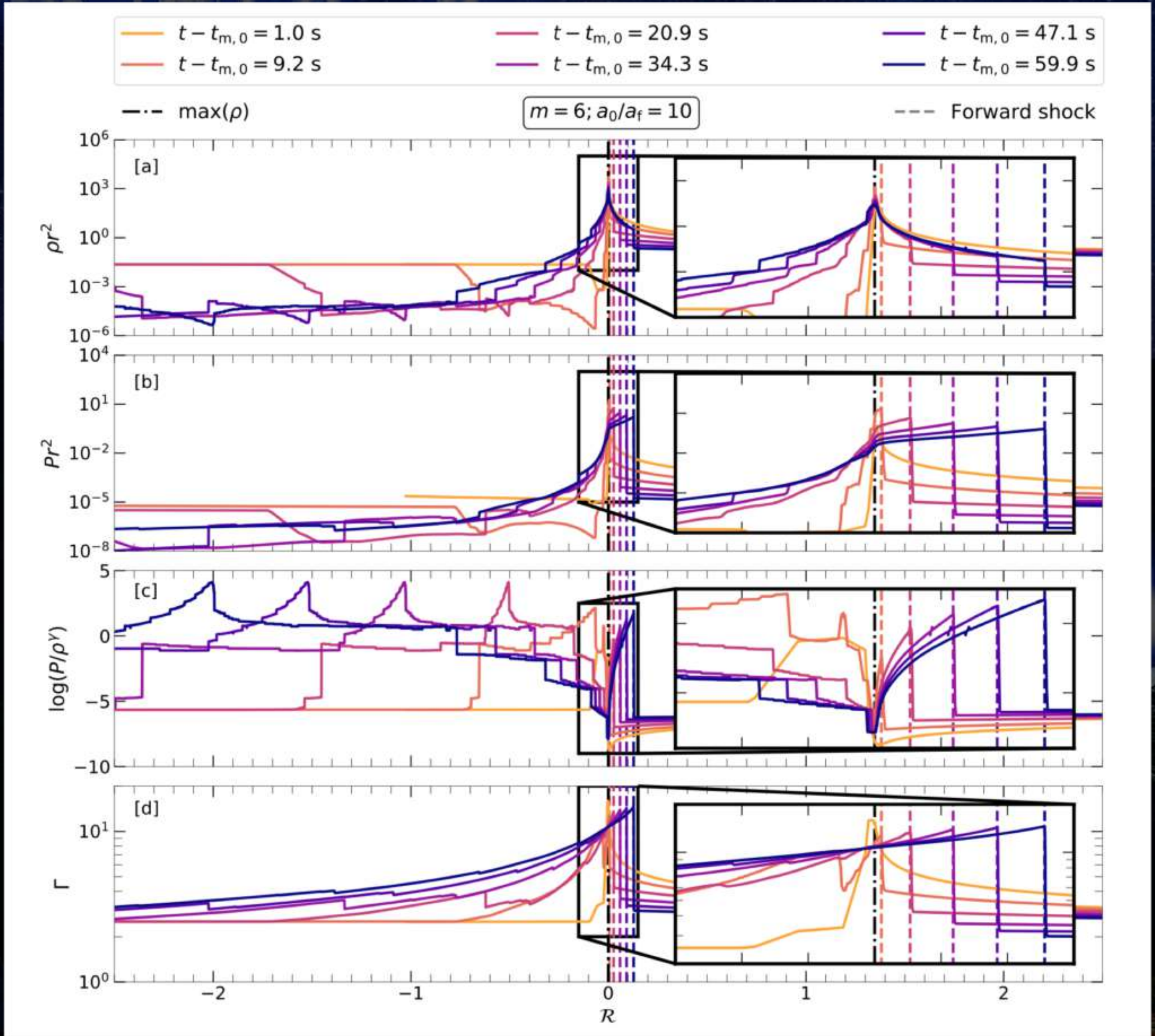
m	Description
> 7	Binary wind decelerates approaching merger; no shocks
< 7	Binary wind accelerates approaching merger; internal shocks
> 5.5	Coasting fast shell
< 5.5	Fast shell sweeps up more than its own inertial mass, decelerates
> 5	Coasting fast shell meets unshocked binary wind
< 5	Coasting fast shell meets earlier-shocked binary wind
< 4	Coasting fast shell sweeps up more than its own rest mass
3	"Goldreich-Julian" scaling (Eq. 11)

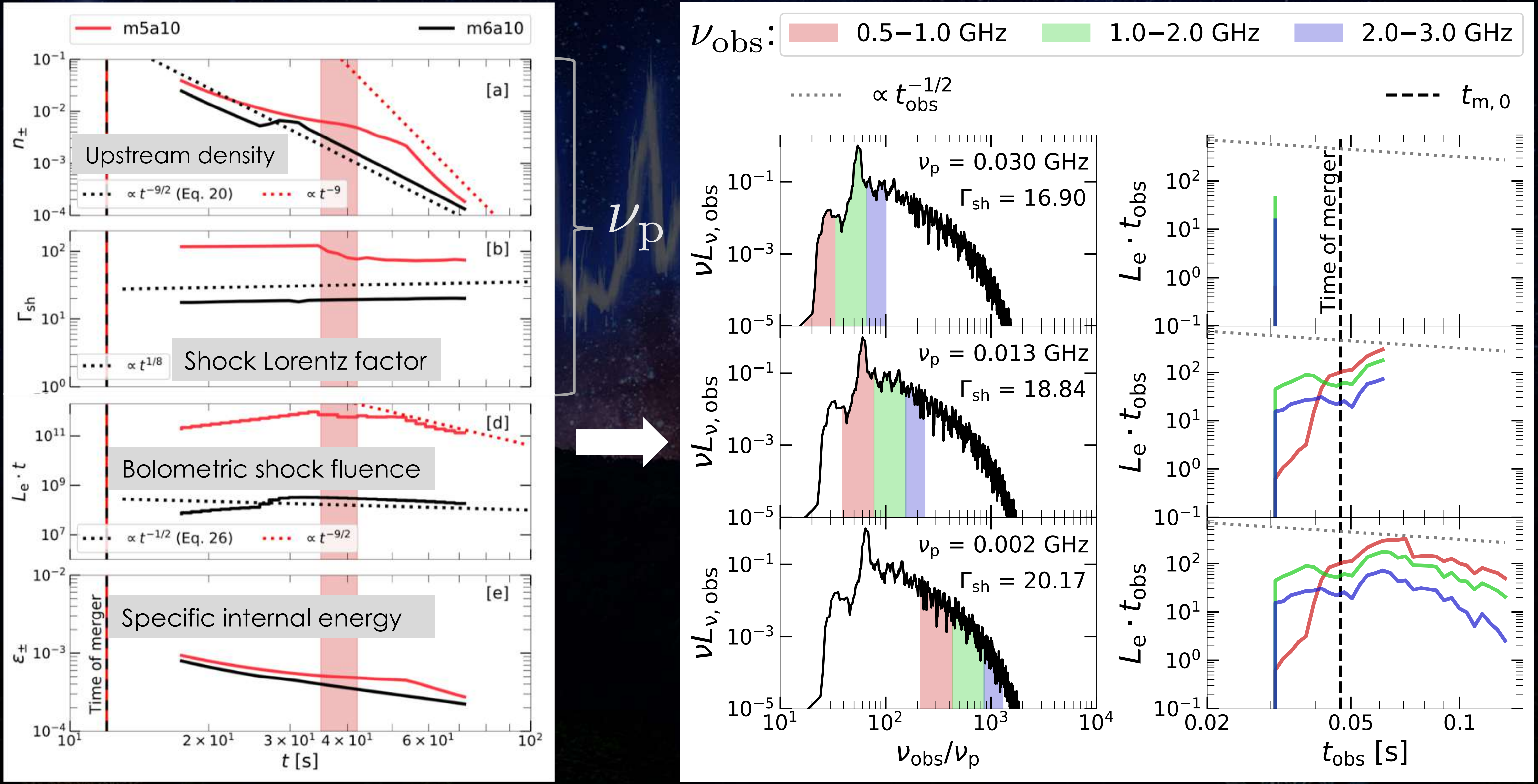


Representative cases:

- m = 5: Decelerating fast shell
- m = 6: Coasting fast shell

Hydrodynamics of wind interaction



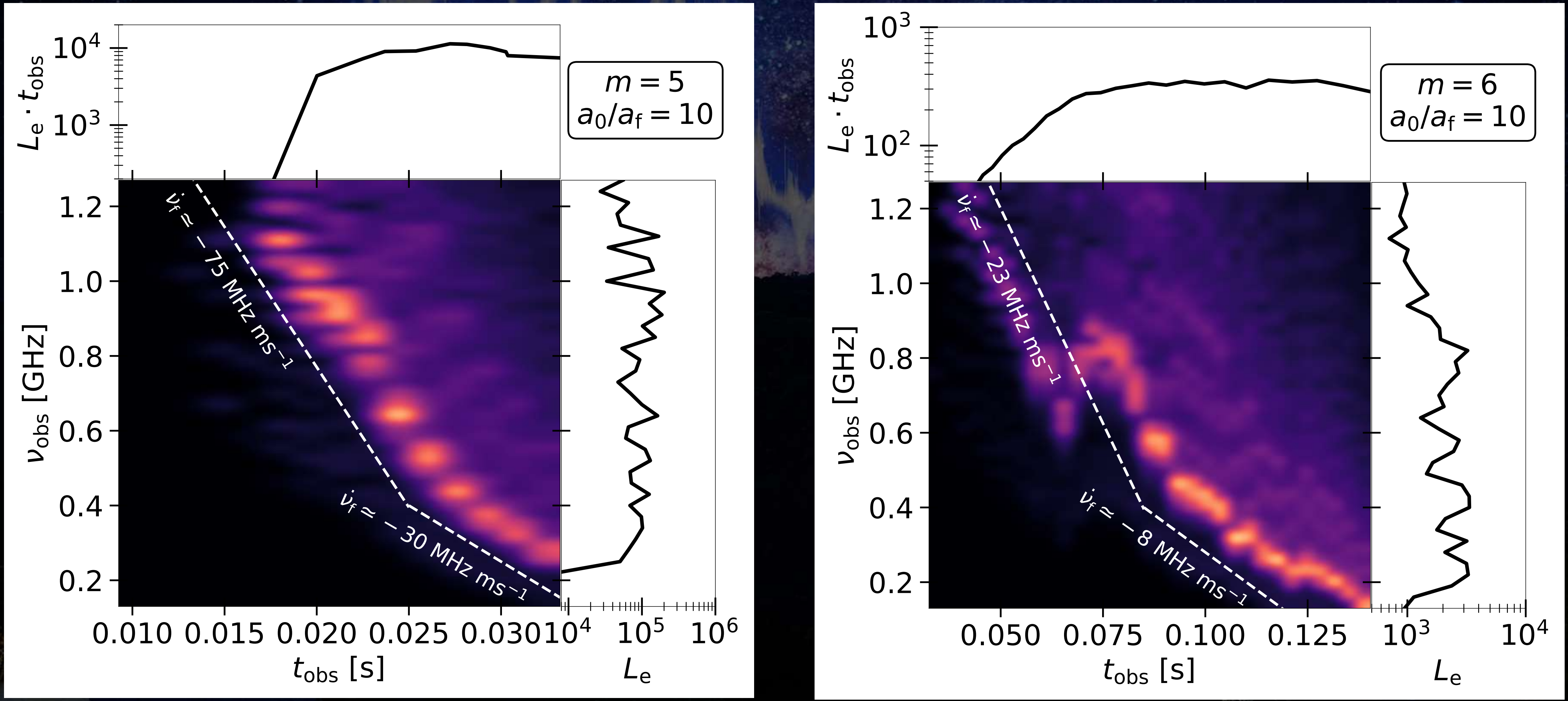


- Hydro simulations supply upstream $n_{\pm}$ and shock $\Gamma_{\rm sh}$ ⇒ Bolometric luminosity (L_e), plasma frequency (ν_p).

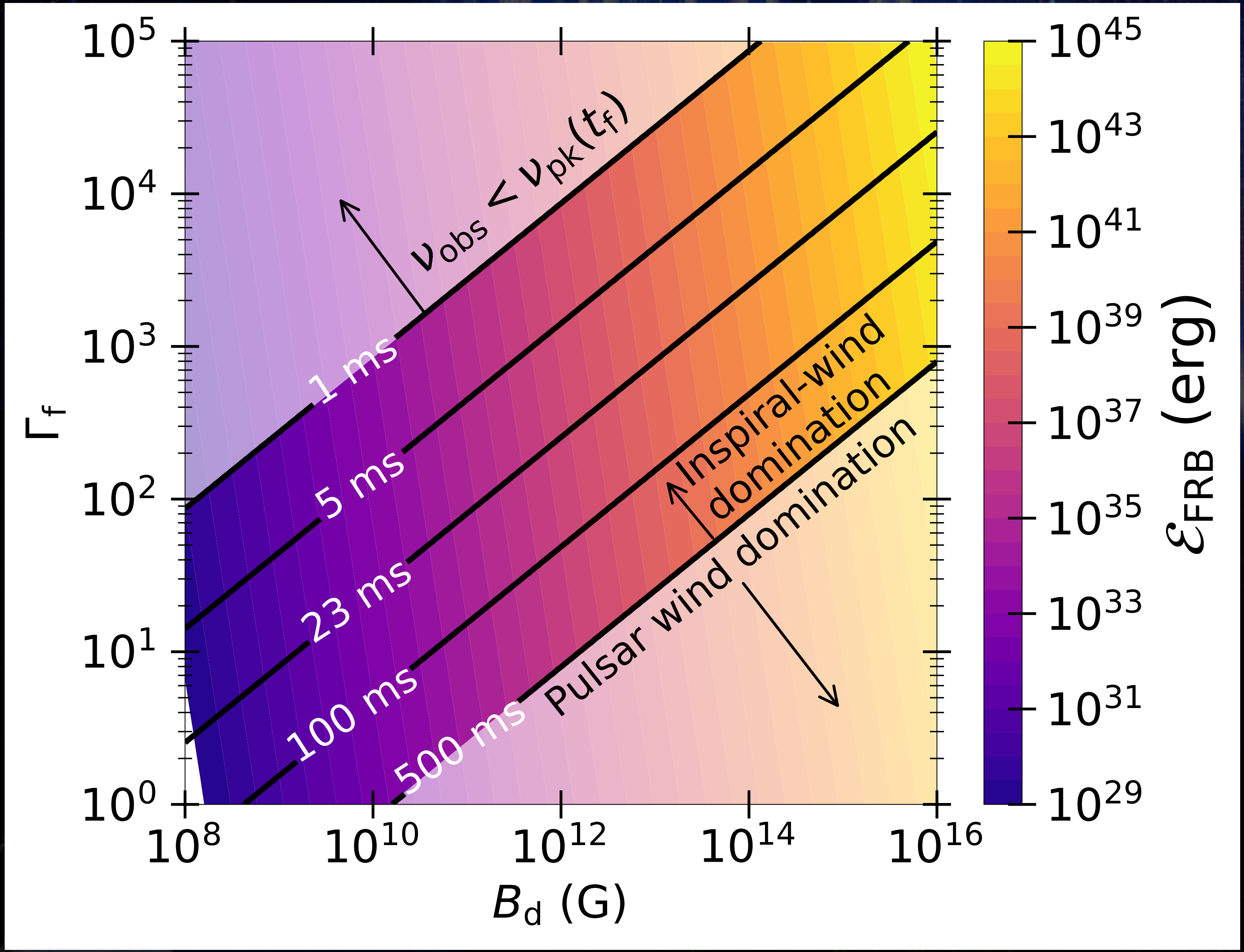
➕ (Plotnikov & Sironi 2019)

- Particle-in-Cell simulation supply the spectrum of synchrotron maser emission ⇒ Radio luminosity!

In-silico FRB!



Engine and observed properties

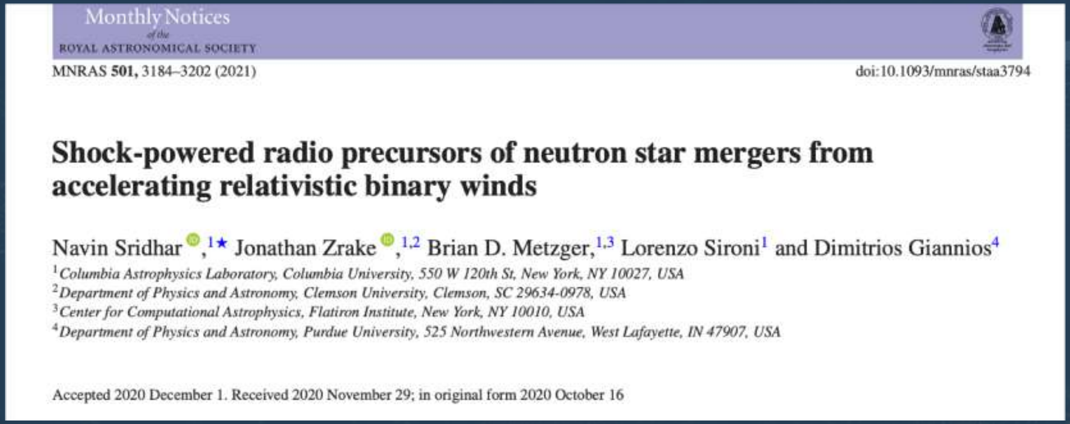


$$\mathcal{E}_{\mathrm{FRB}} \approx L_{\mathrm{r}}[t_{\mathrm{FRB}}]t_{\mathrm{FRB}} \approx 1.2\times 10^{37}\,\mathrm{erg}\left(\frac{f_{\xi,-3}}{f_{\mathrm{b},-1}}\right)\left(\frac{\Gamma_{\mathrm{f}}}{10^3}\right)^{4/9}\left(\frac{\nu_{\mathrm{obs}}}{1\,\mathrm{GHz}}\right)^{2/9}\left(\frac{B_{\mathrm{d}}}{10^{12}\mathrm{G}}\right)^{16/9}$$

$$t_{\mathrm{FRB}} \approx 6.8\,\mathrm{ms}\left(\frac{B_{\mathrm{d}}}{10^{12}\mathrm{G}}\right)^{4/9}\left(\frac{\Gamma_{\mathrm{f}}}{10^3}\right)^{-8/9}\left(\frac{\nu_{\mathrm{obs}}}{1\,\mathrm{GHz}}\right)^{-4/9}$$

Take-away

- A significant fraction ($\sim 10^{-3}$) of the Poynting energy released during NS merger → burst of coherent radio emission.
- The emission will be beamed along orbital plane.
- For $B_d \geq 10^{12}$G, expected fluence ~ 1 Jy ms, from ~Gpc distances.
- ~1% of the observed FRBs (~50 per day) from this channel.
- ~2 per year coincident with GW detections (<150 Mpc).
- The model self-consistently reproduces the key features of FRBs viz., duration, energetics, drifting frequency burst sub-structures.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Shock-powered radio precursors of neutron star mergers from accelerating relativistic binary winds

Navin Sridhar[1★] Jonathan Zrake[1,2] Brian D. Metzger,[1,3] Lorenzo Sironi[1] and Dimitrios Giannios[4]
[1]Columbia Astrophysics Laboratory, Columbia University, 550 W 120th St, New York, NY 10027, USA
[2]Department of Physics and Astronomy, Clemson University, Clemson, SC 29634-0978, USA
[3]Center for Computational Astrophysics, Flatiron Institute, New York, NY 10010, USA
[4]Department of Physics and Astronomy, Purdue University, 525 Northwestern Avenue, West Lafayette, IN 47907, USA

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